

**WHAT IS CLAIMED IS:**

1    1. An apparatus for generating at least one hybrid arc/microwave plasma discharge, the  
2    apparatus comprising:

3        a) a cavity adapted to support at least one of a TE mode and a TM mode at a  
4            microwave frequency; and  
5        b) a torch module, coupled with the cavity, for generating seed plasma within the  
6            cavity.

1    2. The apparatus of claim 1, wherein the cavity is a tapered cavity.

1    3. The apparatus of claim 1, further comprising:

2        c) a microwave source, coupled with the cavity, for generating microwaves at the  
3            microwave frequency, and for introducing the generated microwaves into the  
4            cavity.

1    4. The apparatus of claim 1, wherein the torch module is an arc torch module, and  
2    wherein the seed plasma generated by the arc torch module discharge triggers microwave  
3    discharge in the cavity thereby generating additional plasma.

1    5. The apparatus of claim 4 wherein an exit opening is defined in the cavity at a location  
2    opposite the arc torch module, wherein plasma is generated by a combination of an arc  
3    discharge and microwave discharge, and wherein the generated plasma exits the cavity  
4    through the exit opening as the hybrid arc/microwave discharge.

1    6. The apparatus of claim 1, wherein, said cavity includes a first wall and a second wall  
2    opposing the first wall, wherein the torch module is fitted into the first wall of the cavity,  
3    and wherein an exit opening is defined in the second wall of the cavity at a location  
4    opposed to the location of the torch module.

- 1      7. The apparatus of claim 1, wherein said cavity has a narrow section, a wide section,  
2      and a tapered section arranged between the narrow and wide sections.
  
- 1      8. The apparatus of claim 7 wherein both the narrow section and the wide section have  
2      rectangular cross sections.
  
- 1      9. The apparatus of claim 8, wherein the cavity is dimensioned to support a  $TE_{10n}$  mode  
2      at the microwave source frequency, wherein n is an integer that is at least 3.
  
- 1      10. The apparatus of claim 6, wherein said cavity includes
  - 2            - endwalls substantially orthogonal to the first and second wall, and
  - 3            - additional walls arranged between the endwalls and including the first and
  - 4            second walls,

5                wherein the hybrid arc/microwave plasma discharge exits the cavity from  
6      the exit opening of the second wall.
  
- 1      11. The apparatus of claim 1, further comprising at least one additional torch module  
2      coupled with the cavity, wherein the seed plasma generated by the arc discharges of the  
3      torch modules is energized by a TE mode electric field rather than by a TM mode, the  
4      seed plasma triggering subsequent microwave discharges thereby generating at least two  
5      hybrid arc/microwave plasma discharges.
  
- 1      12. The apparatus of claim 11, wherein, said cavity includes a first wall and a second  
2      wall opposing the first wall, wherein the torch modules are fitted into the first wall of the  
3      cavity, and wherein exit openings are defined in the second wall of the cavity at a  
4      location opposed to the location of the torch modules, wherein said cavity includes  
5      endwalls substantially orthogonal to the first and second walls, and wherein the hybrid  
6      arc/microwave plasma discharges exit the cavity from the two exit holes of the second  
7      wall.

1 13. The apparatus of claim 10, wherein said cavity has a narrow section, a wide section,  
2 and a tapered section arranged between the narrow and wide sections,

3 wherein said cavity includes a narrow section defined by the additional walls, the  
4 narrow section having a height of about 5 mm, a first of the additional walls having a first  
5 opening defined therein at which the torch module is fixed, a second of the additional  
6 walls having a second opening defined therein,

7 wherein the second opening permits the hybrid arc/microwave plasma torch to  
8 exit, and

9 wherein the first and second openings are located at one of the electric field  
10 maximum locations of the  $TE_{10n}$  mode, and the tapered section including two end  
11 locations, the end locations of the taper section located at electric field minimum  
12 locations of said  $TE_{10n}$  mode.

1 14. The apparatus of claim 7, the narrow section has a length of about  $m\lambda_z/2$ , where  $\lambda_z$  is  
2 the wavelength of said  $TE_{10n}$  mode in the axial direction of the cavity, and m is an integer  
3 determined by the number of torches to be hosted in said cavity.

1 15. The apparatus of claim 7, wherein said cavity is a low Q cavity with a value less than  
2 30,

3 wherein said torch module generates seeding plasma generating additional plasma  
4 without requiring microwave breakdown, and

5 wherein said cavity includes an exit opening to exit the hybrid arc/microwave  
6 plasma discharge, said exit opening having a larger diameter than would be possible if  
7 said torch module did not generate seeding plasma, said larger diameter exit opening  
8 resulting in a increase in the size of the plasma discharge.

1 16. The apparatus of claim 1, wherein said torch module includes a frame, a central  
2 electrode, and a ceramic insulator, the frame including an outer electrode which is  
3 electrically connected to the cavity, the ceramic insulator insulating the central electrode  
4 from the frame of the module and from the cavity.

- 1 17. The apparatus of claim 16, wherein said torch module frame includes openings to
- 2 couple inlet gas into a gas chamber of said torch module.
  
- 1 18. The apparatus of claim 1, wherein the hybrid arc/microwave plasma discharge forms
- 2 a column, said column reaching a height of about 6 cm and a diameter of about 2 cm.
  
- 1 19. The apparatus of claim 1, wherein the hybrid arc/microwave plasma torch has a
- 2 density of at least  $10^{13}$  electrons/cm<sup>3</sup>.
  
- 1 20. The apparatus of claim 3, further comprising:
  - 2 d) a first power supply module to power the microwave source; and
  - 3 e) a second power supply module to power the torch module,

4 wherein the first and second power supply modules share a common

5 transformer.
  
- 1 21. The apparatus of claim 20, wherein primary input power is selected from at least one
- 2 of a 60Hz, 50Hz, and 400Hz AC primary power source, wherein the time average power
- 3 of approximately 700W is supplied by said first power supply module, and wherein
- 4 hybrid arc/microwave discharge has a cycle energy of approximately 12 J/cycle.
  
- 1 22. The apparatus of claim 20, wherein, the first power supply module includes a
- 2 coupling capacitor of approximately 1 micro-Farad, wherein the second power supply
- 3 includes a coupling capacitor of 1 micro-Farad and a limiting resistor of approximately
- 4 750 ohms, and wherein the common transformer has a turns ratio of approximately 1:25.
  
- 1 23. The apparatus of claim 3, wherein the cavity is dimensioned to support a TE<sub>10n</sub> mode
- 2 at the microwave source frequency, where n = 3, wherein the microwave frequency is
- 3 approximately 2.45 GHz, and wherein the cavity includes a first section, a second
- 4 section, and a third section, said first section having the dimensions of a S-band WR-284
- 5 waveguide of approximately 7.2 cm x 3.4 cm and a length of approximately 8.74 cm, said
- 6 third section having the dimensions of approximately 7.2 cm x 0.5 cm and a length of

7 approximately 11.65 cm, said second section being a middle section, being tapered,  
8 having a width of approximately 7.2 cm, a height ranging from approximately 3.4 cm to  
9 approximately 0.5 cm, a length of approximately 11.65 cm and a slope angle of  
10 approximately 14 degrees.

1 24. An apparatus for supporting generation of at least one hybrid arc/microwave plasma  
2 discharge, the apparatus comprising:

3 a) a cavity supporting at least one of a TE mode and a TM mode at a microwave  
4 frequency; and  
5 b) means for coupling at least one torch module to said cavity.

1 25. The apparatus of claim 24, wherein the means for coupling at least one torch module  
2 include a threaded portion attached to a wall of said cavity.

1 26. The apparatus of claim 24, wherein the dimensions of the cavity support a  $TE_{10n}$   
2 mode at the microwave source frequency, where n is an integer of at least 3.

1 27. The apparatus of claim 24, further comprising:

2 c) means for coupling at least one additional torch module to said cavity, wherein  
3 said torch plasma is energized by a TE mode electric field rather than by a TM  
4 mode, and wherein at least two hybrid arc/microwave plasma discharges are  
5 generated.

1 28. The apparatus of claim 24, wherein, said cavity includes a first wall and a second  
2 wall opposing the first wall, wherein the means for coupling is provided on the first wall  
3 of the cavity, and wherein an exit opening is defined in the second wall of the cavity at a  
4 location opposed to the location of the means for coupling.

1 29. The apparatus of claim 24, wherein said cavity has a narrow section, a wide section,  
2 and a tapered section arranged between the narrow and wide sections.

- 1 30. The apparatus of claim 29 wherein both the narrow section and the wide section have
- 2 rectangular cross sections.
  
- 1 31. The apparatus of claim 30, wherein the cavity is dimensioned to support a  $TE_{10n}$
- 2 mode at the microwave source frequency, wherein n is an integer that is at least 3.
  
- 1 32. The apparatus of claim 28, wherein said cavity includes endwalls substantially
- 2 orthogonal to the first and second walls, wherein torch plasma forming the hybrid
- 3 arc/microwave plasma discharge exits the cavity from the exit opening of the second
- 4 wall.
  
- 1 33. The apparatus of claim 32, wherein said cavity has a narrow section, a wide section,
- 2 and a tapered section arranged between the narrow and wide sections,  
3 wherein said cavity includes a narrow section defined by the additional walls, the  
4 narrow section having a height of about 5 mm, a first of the additional walls having a first  
5 opening defined therein at which the torch module is fixed, a second of the additional  
6 walls having a second opening defined therein,  
7 wherein the second opening permits the hybrid arc/microwave plasma discharge  
8 to exit, and  
9 wherein the first and second openings are located at one of the electric field  
10 maximum locations of the  $TE_{10n}$  mode, and the tapered section including two end  
11 locations, the end locations of the taper section located at electric field minimum  
12 locations of said  $TE_{10n}$  mode.
  
- 1 34. The apparatus of claim 29, the narrow section has a length of about  $m\lambda_z/2$ , where  $\lambda_z$
- 2 is the wavelength of said  $TE_{10n}$  mode in the axial direction of the cavity, and m is an
- 3 integer determined by the number of torches to be hosted in said cavity.